Journalism and Mass Communication, July-Aug. 2024, Vol. 14, No. 4, 232-240
doi: 10.17265/2160-6579/2024.04.003

# Model of Mediating Determinants of Time Differences in INDYCAR

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The IndyCar series distinguishes itself by providing the same design and operation of the single-seater to its pilots. The difference in times is then attributable to the skills of the drivers, but considering the data from the races could test this assumption. The objective of this work was to establish a trajectory model to predict race times. A cross-sectional, correlational, and explanatory work was carried out with a sample of 18,474 records in the period from 2020 to 2023 of the IndyCar series. The results show that the time span predicts the time differences. In relation to the studies of acceptance of the technology, the adjustment of this to human capacities to explain the time differences in the series of racing cars is discussed.

*Keywords:* time differences, ranking differences, ranking, race time, laps completed

## Introduction

Electrical mechanical engineering is a branch of engineering that combines knowledge of mechanical engineering and electrical engineering (Khedkar et al., 2022). It focuses on the design, development, and maintenance of systems that involve both mechanical and electrical components. This area of engineering is especially relevant today due to the growth of technology and electrification in various industries. In relation to racing cars, electrical mechanical engineering also plays a crucial role in its development. Modern racing cars

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use advanced technology to improve performance, efficiency, and safety. Some key areas where electrical mechanical engineering has a significant influence on racing cars are:

Electric propulsion: Electric propulsion technology has gained popularity in racing cars due to its ability to deliver high levels of performance and efficiency (Piperidis et al., 2020). Electrical mechanical engineering deals with the design and optimization of electric motor systems, high-performance batteries, and energy management systems.

On-board electronics and telemetry: Modern racing cars are equipped with advanced electronics and telemetry systems that allow team engineers to monitor and adjust vehicle performance in real time during races (Dolara et al., 2021). This includes optimization of parameters such as aerodynamics, power distribution, and powertrain control.

Computer-aided design and simulation: Electrical mechanical engineering employs computational modeling and simulation techniques to improve the design and performance of racing cars (Gadola, Chindamo, & Lenzo, 2021). This includes simulation of aerodynamic flow, structural strength, and vehicle dynamics.

Energy recovery systems: Modern racing cars also use energy recovery systems, such as KERS (Kinetic Energy Recovery System) or ERS (Energy Recovery System), which convert kinetic energy during braking into electrical energy stored in batteries (Ballo, Stabile, Gobbi, & Mastinu, 2022). Electrical mechanical engineering plays an important role in the design and optimization of these systems.

Safety and control: Electrical mechanical engineering is also applied in the improvement of safety and control systems in racing cars, such as anti-lock braking systems (ABS), traction control and stability control systems (Srivastava et al., 2020).

Electrical mechanical engineering plays a fundamental role in the evolution of racing cars towards more efficient, faster, and safer vehicles, taking advantage of technological advances in electrification and computing to achieve better results on racetracks (Țoțu & Alexandru, 2023). Engineering plays a fundamental role in improving the performance and competitiveness of racing cars. Engineers work in various areas to make cars win races. Engineers focus on designing aerodynamic bodies and components that reduce air resistance and generate maximum downforce. This improves the stability and adherence of the vehicle to the track, allowing the cars to maintain higher speeds in curves and straightaways. Engineers work on developing and tuning engines to maximize their power and efficiency. The optimization of combustion, air flow, and the intake and exhaust system are some of the key aspects to obtain the maximum performance from the engine.

Racing cars require highly sophisticated and adjustable chassis and suspension systems (Carrasco Garcí a et al., 2022). Engineers are tasked with designing systems that allow for precise handling and proper distribution of wheel load to improve grip and traction. Engineers work on advanced drivetrain and braking systems to optimize power transfer to the wheels and enable effective and precise braking, which is crucial for racing performance.

Track engineers use telemetry systems to monitor in real time the performance of the car during the race (Harshavardhan et al., 2021). Using this data, they can adjust race strategy and make recommendations to the driver to optimize performance and efficiency during competition. Engineers use computational modeling and simulation tools to test different vehicle configurations and settings prior to races. This allows them to predict the car’s performance and make virtual design changes to improve its performance. Tire engineers work in collaboration with manufacturers to develop tires specifically for the conditions and characteristics of racetracks. The right tires are crucial to achieving maximum grip and durability during competitions.

In racing, the main goal is to win, and to achieve this, cars need to be as fast and efficient as possible (Sreevatsan et al., 2022). Engineering focuses on optimizing every aspect of the vehicle to get the best performance in the shortest possible time. A racing car needs to be fast, but it also needs to be efficient and durable to complete the race smoothly. Engineering is concerned with maximizing the efficiency of the systems and making sure that the car's components can withstand the extreme conditions and stress of a race.

The time of the race influences the strategy that the teams must follow during the competition (Parmar, Desai, Patel, & Patel, 2020). Engineering plays an essential role in data analysis and strategic decision making, such as when to make pit stops, which tries to use, and how to optimize vehicle performance at different points in the race. Pit stops are critical moments in a race. Engineering is focused on minimizing the time the car spends in the pits during refueling, tire changes, and vehicle tune-ups. Engineering is also applied in the design of racetracks and the planning of fastest laps. Proper track and corner layout can have a significant impact on lap times and therefore race results.

Engineering uses telemetry systems to collect data in real time during the race (Pouansi Majiade & Eckstein, 2022). Engineers monitor and analyze this data to fine-tune the car's performance and improve its lap time, which can make the difference between winning or losing. The race time acts as a reference point for the continued development of racing cars. The results obtained on the track help engineers identify areas for improvement and work on new technologies and approaches to increase the speed and efficiency of vehicles in future competitions.

Race time is crucial for the engineering of racing cars because it drives the competitiveness, efficiency, and performance of the vehicle, and guides the continuous development to stay ahead in the world of motorsports competitions (Țoțu & Alexandru, 2021). The measurement of the competitiveness, efficiency, and performance of racing cars is a fundamental part of the analysis and improvement of their performance. To achieve this, various engineering and telemetry techniques and tools are used. The time it takes a car to complete a lap on the track is a key indicator of its performance. Comparing lap times between different cars allows you to assess their relative competitiveness. The top speed achieved on long straights provides an indication of engine power and efficiency, as well as the vehicle's aerodynamics.

Acceleration and braking ability are essential in racing. Times and distances are measured to assess the efficiency and performance of the propulsion and braking systems (Torres, Rockwood, & Maldonado, 2022). Modern racing cars are equipped with telemetry systems that collect data in real time during competition. This includes information about engine temperature, speed, tire pressure, fuel flow, and other relevant parameters. Track engineers analyze this data to adjust strategies and optimize car performance.

Once the race is finished, a thorough analysis of the collected data is carried out (Trzesniowski, 2023). This helps to understand how the car performed during competition and to identify areas for improvement. Simulation and modeling tools are used to predict the performance of the car in different scenarios and configurations. This allows virtual adjustments to be made before applying changes to the actual vehicle.

Data collected from own cars are compared with that of the competition to assess relative competitiveness and look for strengths and weaknesses compared to other teams (Thakur, Verma, Angral, & Ahanger, 2020). Wear on vehicle components such as tires, brakes, and engines are monitored to ensure they are reliable and efficient throughout the race. The career strategy used is analyzed to determine if it was effective in terms of competitiveness and efficiency.

Measuring the competitiveness, efficiency, and performance of racing cars involves a combination of real-time data, post-race analysis, and advanced simulation tools (Yadav, Saini, & Chaudhary, 2022). Studies are focused on understanding how body design and aerodynamic components affect air resistance and downforce generation to improve stability and performance on the track. Research focuses on the development and optimization of propulsion systems, including internal combustion engines, electric propulsion systems, and energy recovery systems. Research is conducted on the use of lightweight and strong materials to reduce the overall weight of the vehicle and improve the power-to-weight ratio, which contributes to better performance on the track.

The dynamics of racing cars are studied, including cornering behavior, wheel load distribution and stability in different driving situations (Zhang et al., 2022). Research is focused on developing advanced safety systems, such as head protection devices (HANS), survival cells, and restraint systems, to improve pilot safety in the event of an accident. The studies focus on the analysis of real-time and post-race data collected through telemetry systems to optimize race strategy and vehicle performance.

The behavior of tires in different track conditions is investigated and the wear of other components is analyzed to improve durability and efficiency during races (Das et al., 2023). Advanced modeling and simulation tools are used to predict the car's performance in different scenarios and configurations, helping to make more informed design and strategy decisions.

IndyCar is a single seater racing series that takes place primarily in the United States (McCarrison, 2021). The cars that compete in this series are designed to maximize performance and safety on different circuits, such as ovals and permanent or urban circuits. IndyCar cars use carbon fiber chassis that offer high rigidity and strength, while being lightweight to improve performance and safety. Aerodynamic design is a critical aspect of IndyCar cars. Engineers are focused on developing bodies and components that generate the right amount of downforce to improve road holding and allow the cars to drive at high speeds through corners. IndyCar cars use highly sophisticated suspension systems that allow height and stiffness to be adjusted to suit different types of tracks and conditions. Advanced braking systems are employed to achieve effective and safe deceleration during races.

IndyCar cars use an technology that controls and manages a variety of systems, including fuel injection, ignition, and other electronic components (Jebakumar, Pashilkar, & Sundararajan, 2022). IndyCar cars are equipped with telemetry systems that collect data in real time during races. This information is used to monitor and adjust the performance of the car and for strategic decision making. Drivers are provided with displays and controls on the steering wheel that provide them with important information about the condition of the car and allow them to adjust during the race.

Data acquisition systems are used to collect and analyze detailed information about the car's performance in different racing situations (Kulkarni et al., 2020). Modern racing cars are equipped with telemetry systems that collect data in real time during competition. These systems send information back to the team base while the car is on the track, allowing vehicle performance to be monitored and strategy to be adjusted in real time. Global Positioning Systems (GPS) and precise timing systems are used to measure lap times and other data related to the speed and acceleration of the car at different points on the track. Racing cars are equipped with a wide variety of sensors that measure parameters such as engine temperature, tire pressure, wheel speed, and other crucial data to assess car performance. Data acquisition systems are used to record and analyze detailed information about the behavior of the car, such as engine rotation speed, fuel pressure, oil temperature, among others.

Engineers use computational modeling and simulation tools to predict the performance of the car in different scenarios and configurations before making actual changes to the vehicle (Jin et al., 2022). Teams of engineers and analysts review and process data collected during testing and racing to gain valuable insight into car performance and efficiency. Engineers use specialized equipment to evaluate tire behavior under different track conditions and analyze tire wear.

However, the results of the races such as the ranking, the complete laps, the time lapses, the difference ranking have established the prediction of the difference time, an indicator of efficiency, competitiveness, performance, and safety (Deng, 2021). In this way, the objective of the study is to establish a predictive model with mediating factors of the time differences of the racing cars in the IndyCar in order to generate strategies for the improvement of the mechanical and electrical engineering of single seaters.

Are there significant differences between the theoretical structure of the time differences of the IndyCar cars with respect to the records of the races from 2020 to 2023?

Hypothesis 1. Time lapses and ranking differences carry over the effect of completed races and driver ranking.

Hypothesis 2. The time differences between the racing cars are explained from the interaction between the completed races and the time lapses, or, between driver ranking and ranking differences.

Hypothesis 3. The interrelationships between driver ranking, ranking differences, and number of races completed between drivers explain the time differences.

## Method

### Design

An explanatory, cross-sectional, and correlational study was carried out with a sample of IndyCar race records provided by indicating 500 data set, considering the period from 2020 to 2023.

### Instrument

The IndyCar 500 record was used which includes a database of 18,474 observations relating to driver ranking, ranking differences, lap time laps, time lap differences, and drivers' completed races.

### Procedure

The data were selected from the kaglee.com repository from the keyword search of "IndyCar" and "racing cars". The databases were selected according to their open use license for scientific, technological, academic, and statistical purposes. From a total of 100 options, the database that offered the details of the records, such as the identification of the observations, the contents, and the replica of use, was selected. Next, experts in the field, through the technique of focus groups and the Delphi technique, homogenized the concepts included in the databases and qualified the contents according to a scale that goes from 0 = "totally unsatisfactory" to 5 = "totally satisfactory". The Benford test was used for the audit and reliability of the data, reaching the values required for the normal distribution. In this way, the first principal digit explained 0.57% of the total percentage, being lower than the expected percentage of 30% according to Benford's Law [$X2 = 34,267.452$ (8gl) $p > 0.001$; No. = 5,769].

### Analysis

The mediation parameters were estimated: direct effects, indirect effects, total effects, total indirect effects, and residual covariances to be able to test the three hypotheses stated at the end of the introduction. Values close to unity were assumed as evidence of non-rejection of the null hypothesis.

## Results

The homogeneous random effects suggest that the relationship between the time lapse variables is determinant of the time differences. This result makes it possible to explain that the system of determinant variables of performance, competitiveness, and security indicated by the time differences is stochastic (see Table 1).

The stochastic effect relationships indicate the possibility of contrasting the hypotheses related to the direct and indirect determinants of the time differences observed in the IndyCar events from 2020 to 2023. In this sense, a trajectory model allowed establishing the effects by comparing them to be able to anticipate opportunity scenarios (see Figure 1). In other words, the empirical model suggests the non-rejection of the hypotheses regarding direct and indirect predictions from the observed determinants.

Table 1

*Homogeneous Random Effects of System Variables*

| Effects | | | Estimate | Error | z | p | Low | High |
|---|---|---|---|---|---|---|---|---|
| Direct | | | | | | | | |
| Laps completed | ⇒ | Time differences | -6.43 | 0.004 | -0.176 | 0.860 | -0.008 | 0.007 |
| Ranking | ⇒ | Time differences | 0.001 | 0.002 | 0.657 | 0.511 | -0.002 | 0.004 |
| Indirect | | | | | | | | |
| Laps completed | ⇒ | Lapse of time | 0.003 | 0.004 | 0.907 | 0.364 | -0.004 | 0.010 |
| Laps completed | ⇒ | Ranking differences | 5.37 | 3.71 | 1,448 | 0.148 | -1,899 | 1,264 |
| Ranking | ⇒ | Lapse of time | 1,241 | 1,379 | 0.900 | 0.368 | -1,462 | 3,943 |
| Ranking | ⇒ | Ranking differences | 0.002 | 3,075 | 7,324 | 0.001 | 0.002 | 0.003 |
| Totals | | | | | | | | |
| Laps completed | ⇒ | Difference time | 0.003 | 2,294 | 11,868 | 0.001 | 0.002 | 0.003 |
| Ranking | ⇒ | Difference time | 0.003 | 0.002 | 2,197 | 0.028 | 3,652 | 0.006 |
| Indirect totals | | | | | | | | |
| Laps completed | ⇒ | Difference time | 0.003 | 0.004 | 0.922 | 0.356 | -0.004 | 0.001 |
| Ranking | ⇒ | Difference time | 0.002 | 3,368 | 7,056 | 0.001 | 0.002 | 0.003 |
| Residual covariances | | | | | | | | |
| Lapse of time | ⇒ | Ranking differences | 2.37 | 7,977 | 0.298 | 0.766 | -0.001 | 0.002 |

*Notes.* Time difference: R2 = 0.049; Time span: R2 = 0.996; Ranking difference: R2 = 0.014. Source: Prepared with study data.

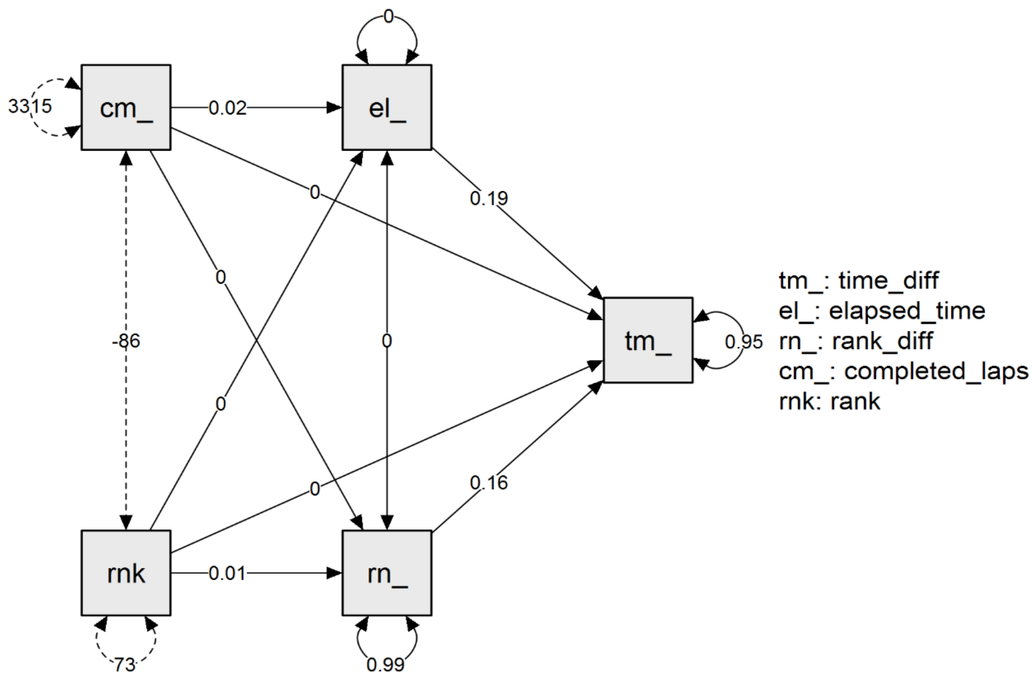


*Figure 1.* Homogeneous random effects. Source: Prepared with study data.

## Discussion

The contribution of the study lies in the contrasting of hypotheses related to the direct and indirect effects of the determinants and mediators of the time differences in the IndyCar circuits. Analysis of direct and indirect effects suggests that time lapse is determinant of time differences. This finding is relevant if one considers that the studies of efficiency, competitiveness, safety, and performance suggest that the acceptance of the technology reflects its usefulness. Furthermore, the trail analysis indicates that the ranking of the differences conveys the effect of the ranking of the driver. That is, the coupling between technology and human skills indicates a feature that distinguishes racing cars from conventional ones. The mechanical and electrical functions of conventional cars are not adjusted to the driver but in racing cars they are coupled to the driver's capabilities. Therefore, the inclusion of driver skills in the proposed model will open the discussion around the adjustment of technologies in driver skills.

However, the mechanical and electrical engineering of the racing cars in the IndyCar series have the same designs and functions, a difference in timing is attributed to the driver's skills, but the adjustment of the design to the capabilities results in a more competitive, advanced, and safe car. Lines of research related to the differences between drivers and the adjustment of their capabilities to technology opens the discussion around a reengineering of functions and processes.

## Conclusion

The objective of the study lies in the demonstration of hypotheses related to the determinants of the time differences in the IndyCar series. The results corroborate the theoretical assumptions and recommend the inclusion of psychological variables that would explain the differences between the travel times in the series. Based on this adjustment between technology and driver capabilities, it is possible to anticipate a competitive scenario. safety and performance that involves the convergence of mechanical and electrical engineering to the capabilities of drivers. Therefore, the inclusion of the variables attributable to human capabilities will explain the time differences in a circuit where all the pilots share the same design and operation of a single seater.

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